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# On the timing history of PSR B1509 − 58

R. D. Blandford
*California Institute of Technology, Theoretical Astrophysics, 130-33, Pasadena, CA 91125, USA*

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**ABSTRACT**

The measurement of the third frequency derivative of PSR B1509 − 58 reported by Kaspi et al. is consistent with a constant magnetic moment. If a more accurate, stable measurement can be made, it should be possible to test directly models in which the magnetic moment varies.

**Key words:** MHD – stars: magnetic fields – pulsars: general – pulsars: individual: B1509 − 58.

## 1 INTRODUCTION

Kaspi et al. (1994) have recently reported a measurement of the third derivative of the spin frequency $\nu$ of the radio pulsar B1509 − 58. They have interpreted this measurement in terms of a simple dynamical model for the pulsar deceleration, namely that $\nu$ ( = 6.64 Hz) varies according to

$$\dot{\nu} = -K(t)\,\nu^{n_0}, \tag{1}$$

where $n_0$ is the deceleration parameter. The motivation for this model (cf. Blandford & Romani 1988) is the hypothesis that there are only two relevant length-scales, the light-cylinder radius and the neutron-star radius $R$. As the former greatly exceeds the latter, the total torque $G$ should only depend upon the lowest contributing magnetic multipole, the dipole $\mu(t)$. On dimensional grounds, it should have the form $G = k(\mu^2/R^3)(2\pi\nu R/c)^{n_0}$, where $k$ is a numerical constant. This is equivalent to equation (1). Departure from a power-law variation would require the introduction of a third length-scale into the problem. In fact, the *variety* of measured deceleration parameters for other pulsars $(2.02 < n < 2.83)$ already suggests that either the dynamical model represented by equation (1) is not generally valid, or that magnetic moment variation is widespread. (This may, however, be caused by variation of the magnetic inclination rather than growth or decay of the field strength.)

The function $K(t)$ therefore describes secular changes in the dipole moment $\mu$, and if it is not constant the true deceleration parameter $n_0$ will differ from the measured quantity $n = \ddot{\nu}\nu/\dot{\nu}^2$. In addition, the measured *jerk parameter* $m = \dddot{\nu}\nu^2/\dot{\nu}^3$ will differ from the prediction $m_0 = 2n^2 - n$ based upon a constant value for $K$. Kaspi et al. report that $n = 2.837 \pm 0.001$ and $m = 14.5 \pm 3.6$. This is formally consistent with the value $m_0 = 13.3$ derived assuming that $K$ is a constant. As Kaspi et al. emphasize, the error may decrease as the number of observations increases to give a stable measurement of $m$ that is significantly different from $m_0$. Alternatively, it may be a manifestation of timing noise, as is probably the case for an analogous measurement of the third derivative in the case of the Crab pulsar (Lyne, Pritchard & Smith 1988). In this case, $\dddot{\nu}$ will change as the data span increases. For the moment, let us explore the consequence of a stable measurement of $\dddot{\nu}$.

## 2 CALCULATIONS

If instead of regarding $K$ as a function of time we treat it as a function of frequency *following the actual spin evolution of this pulsar,* then it is straightforward to show that

$$\frac{\mathrm{d}\ln K}{\mathrm{d}\ln\nu} = n - n_0,$$
$$\frac{\mathrm{d}^2\ln K}{\mathrm{d}\ln\nu^2} = m - m_0. \tag{2}$$

As we are unable to calculate $n_0$ theoretically, measurement of $n$ does not allow us to compute $\mathrm{d}\ln K/\mathrm{d}\ln\nu$, and so we cannot argue that the magnetic moment is changing now. However, what is important is that $\mathrm{d}^2\ln K/\mathrm{d}\ln\nu^2$ *is independent of* $n_0$. If it is found to differ from zero, and that our dynamical model is valid, then the magnetic moment must have changed in the past. In particular, if the field grows rapidly in a pulsar and then gradually decays (cf. Romani 1990), then we expect that $m < m_0$. In this connection, we note that PSR B1509 − 58 has an unusually large dipole moment of $2 \times 10^{31}$ G cm$^3$, suggesting that it is near the maximal value.

The pulsar B1509 − 58 was invoked by Blandford, Applegate & Hernquist (1983) as providing circumstantial evidence for growth of neutron-star magnetic fields because it is associated with a supernova remnant, MSH 15 − 52, that appeared to be significantly older than the formal pulsar spin-down age of $\nu_0/(n-1)\dot{\nu}_0 = 1691$ yr (cf. Seward & Harnden 1982; van den Bergh & Kamper 1984). Conversely, Thorsett (1992) proposed an identification with SN AD185, which would give a more similar age of 1808 yr. To what extent do the present observations illuminate this debate? The most that can be done with the information at our disposal is to make a Taylor expansion of $K$ along the evolutionary trajectory to second order. If we suppose that the pulsar was born with a frequency $\nu_i$, then

$$T \simeq \frac{\nu_0}{\dot{\nu}_0} \int_1^{\nu_i/\nu_0} \frac{dx}{x^{n_0}} \left[\frac{K(\nu_0)}{K(x\nu_0)}\right]$$
$$\simeq \frac{\nu_0}{\dot{\nu}_0} \int_0^{\ln(\nu_i/\nu_0)} dy \exp[-(n-1)y-(m-m_0)y^2/2], \tag{3}$$

where we have used equation (2). This integral is elementary but *also independent of* $n_0$. If we adopt the measured value of $m$ and assume that $\nu_i \gg \nu_0$, then $T=1350$ yr. In general, values of $m$ larger than $m_0$ will reduce the inferred age; a slightly smaller value will render its age consistent with the historical estimate and a substantially smaller value will favour the field-growth model.

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